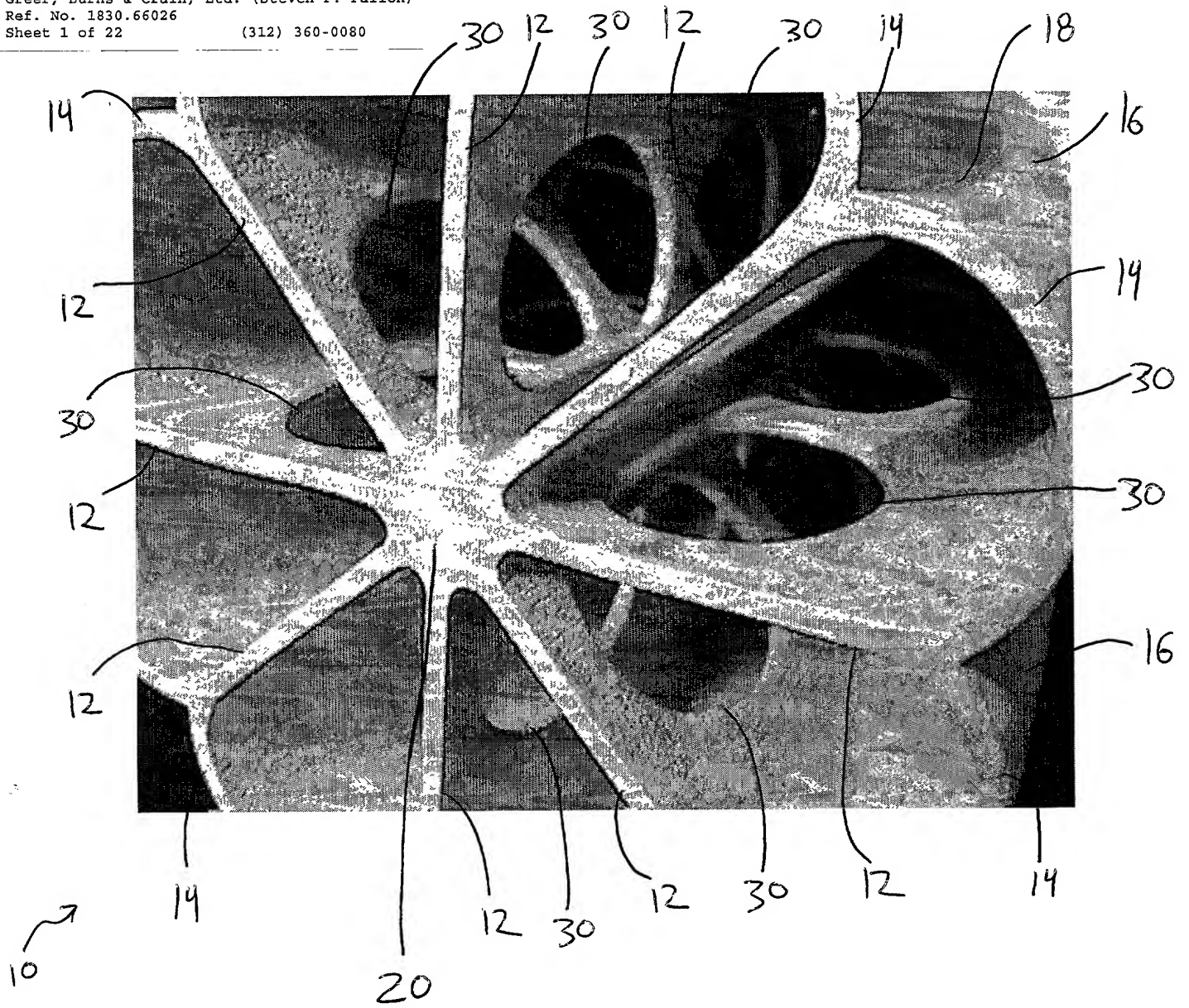


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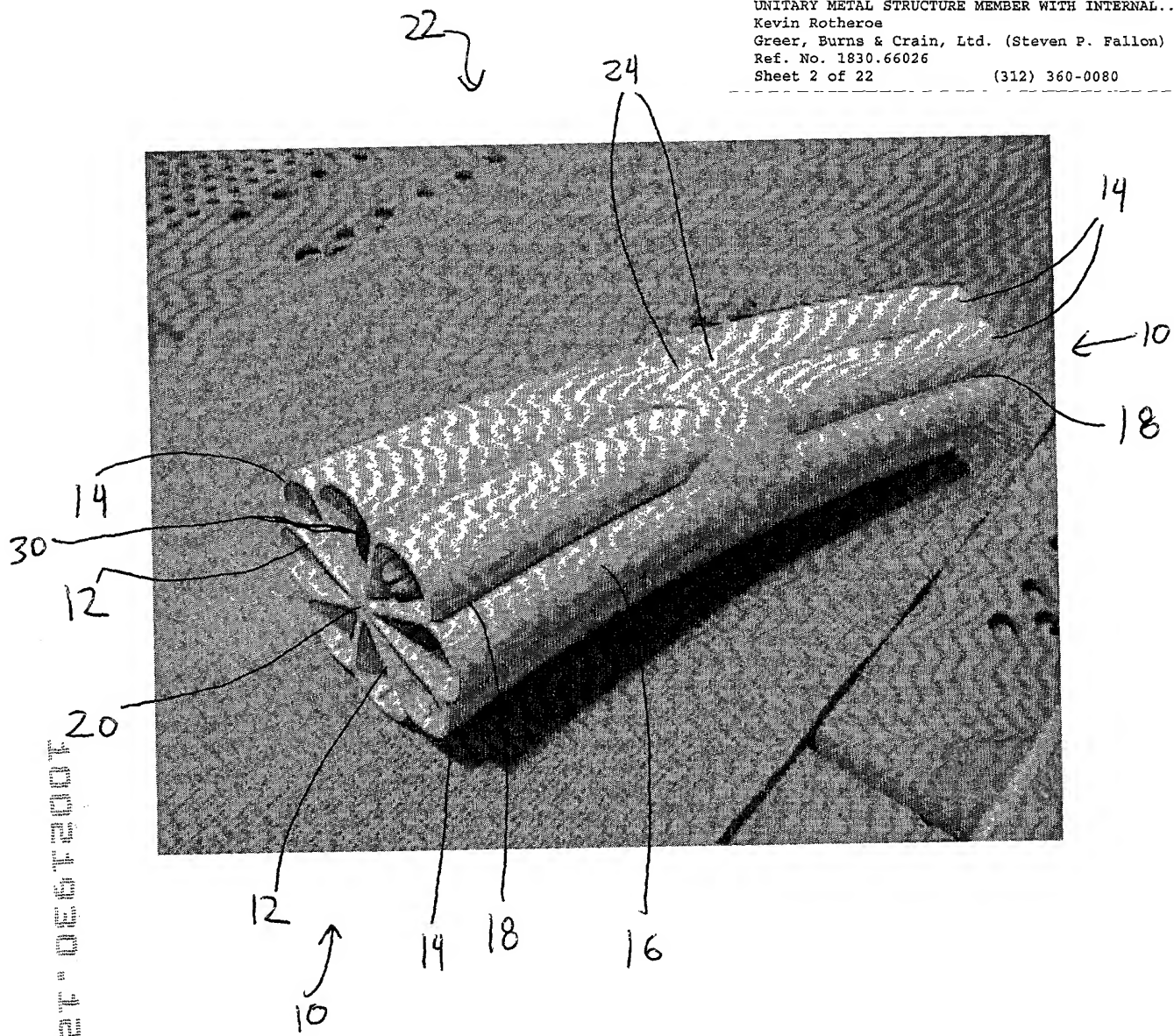


FIG. 2

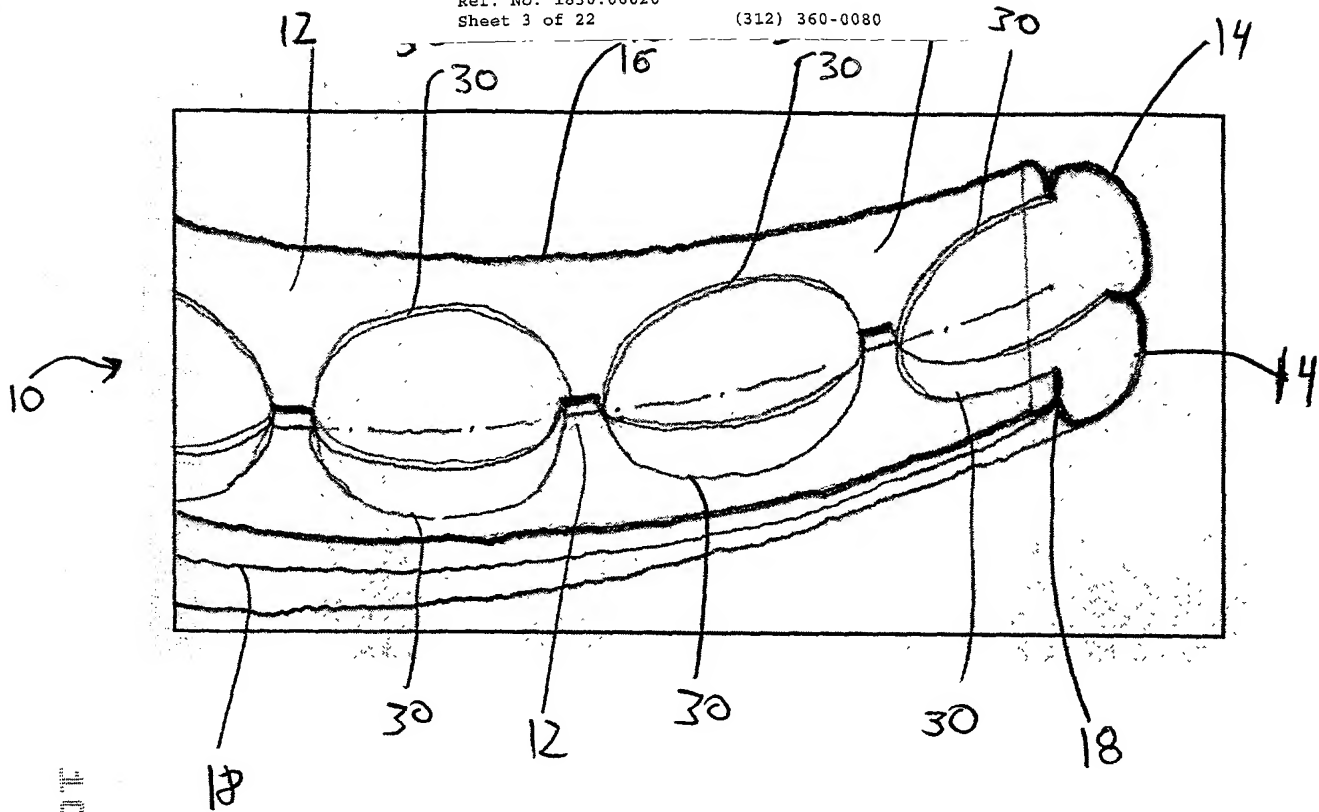


FIG. 3

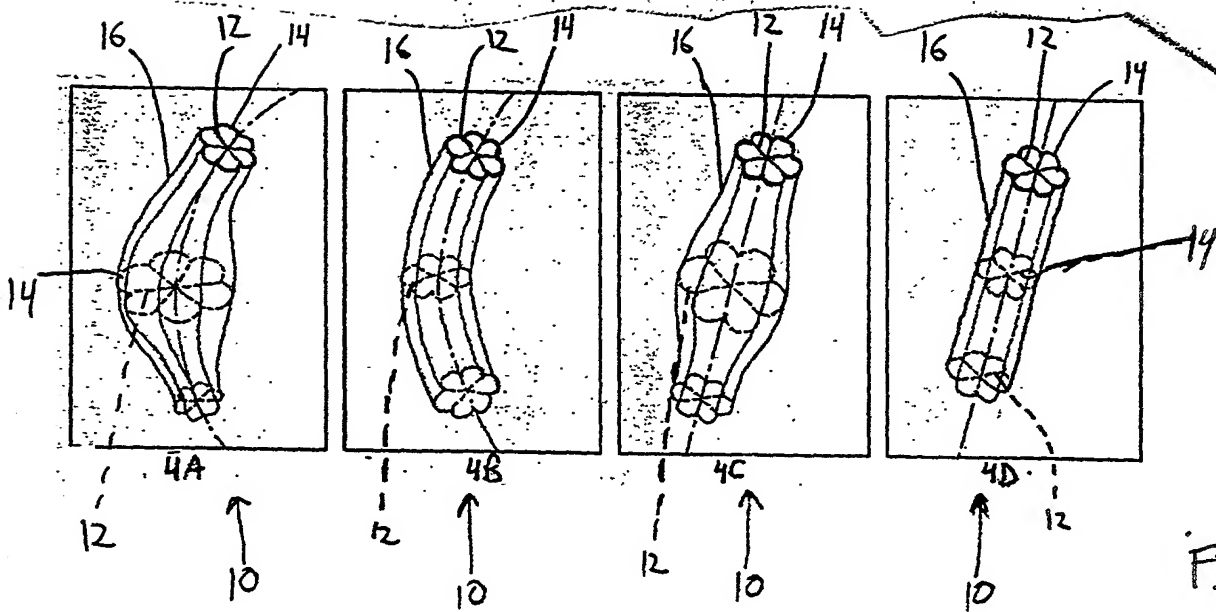
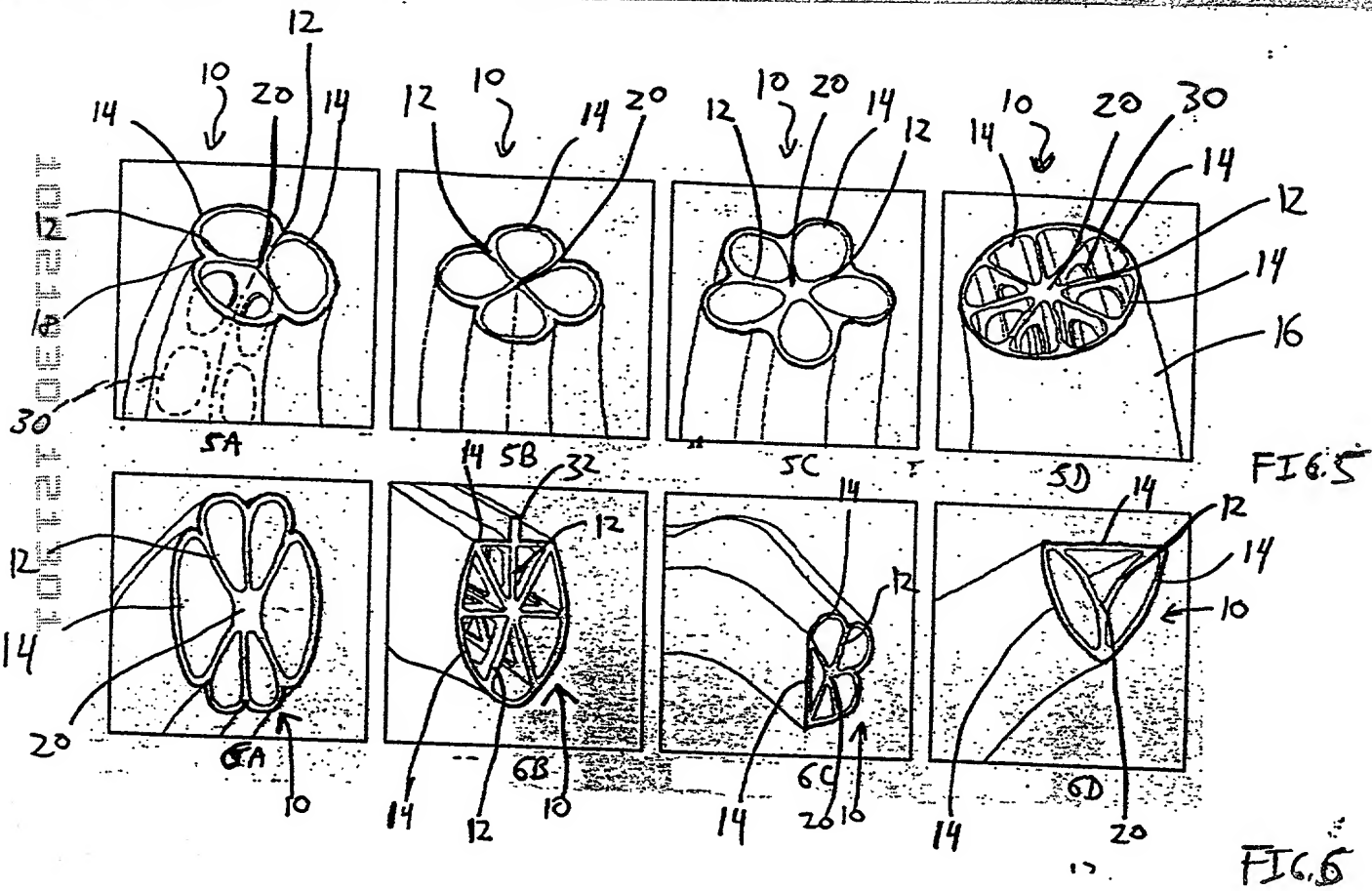


FIG. 4



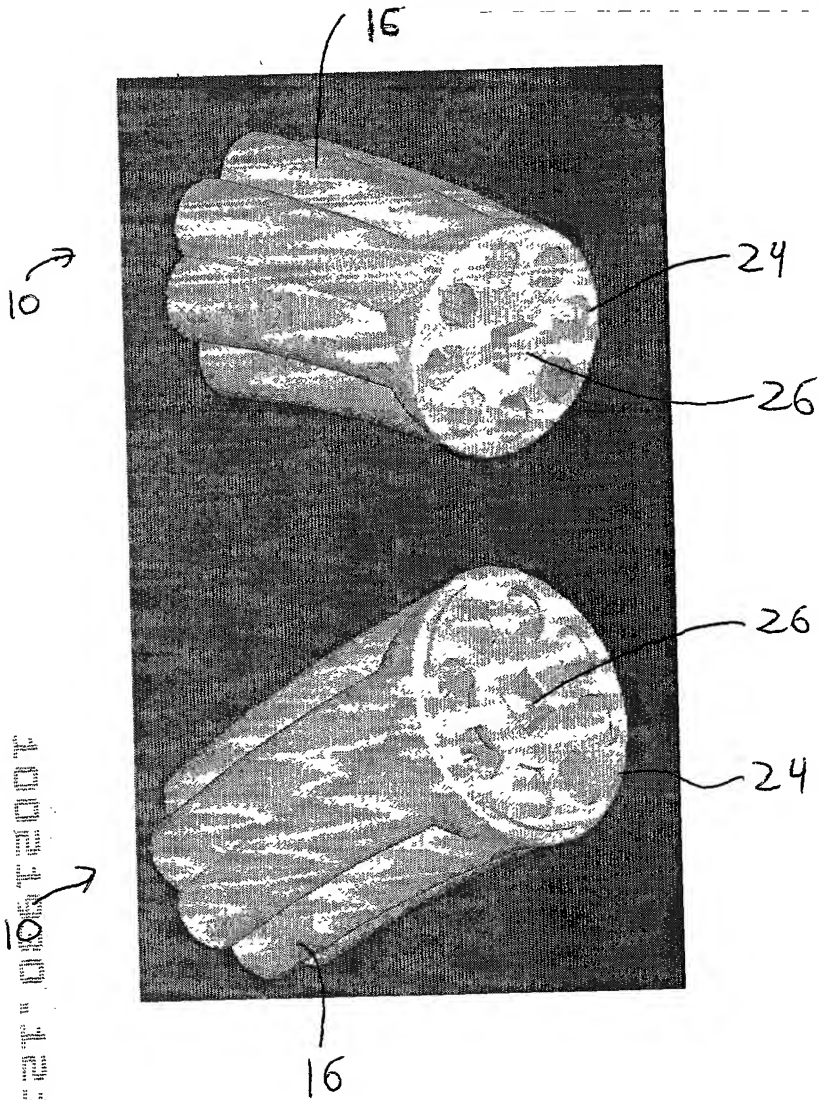
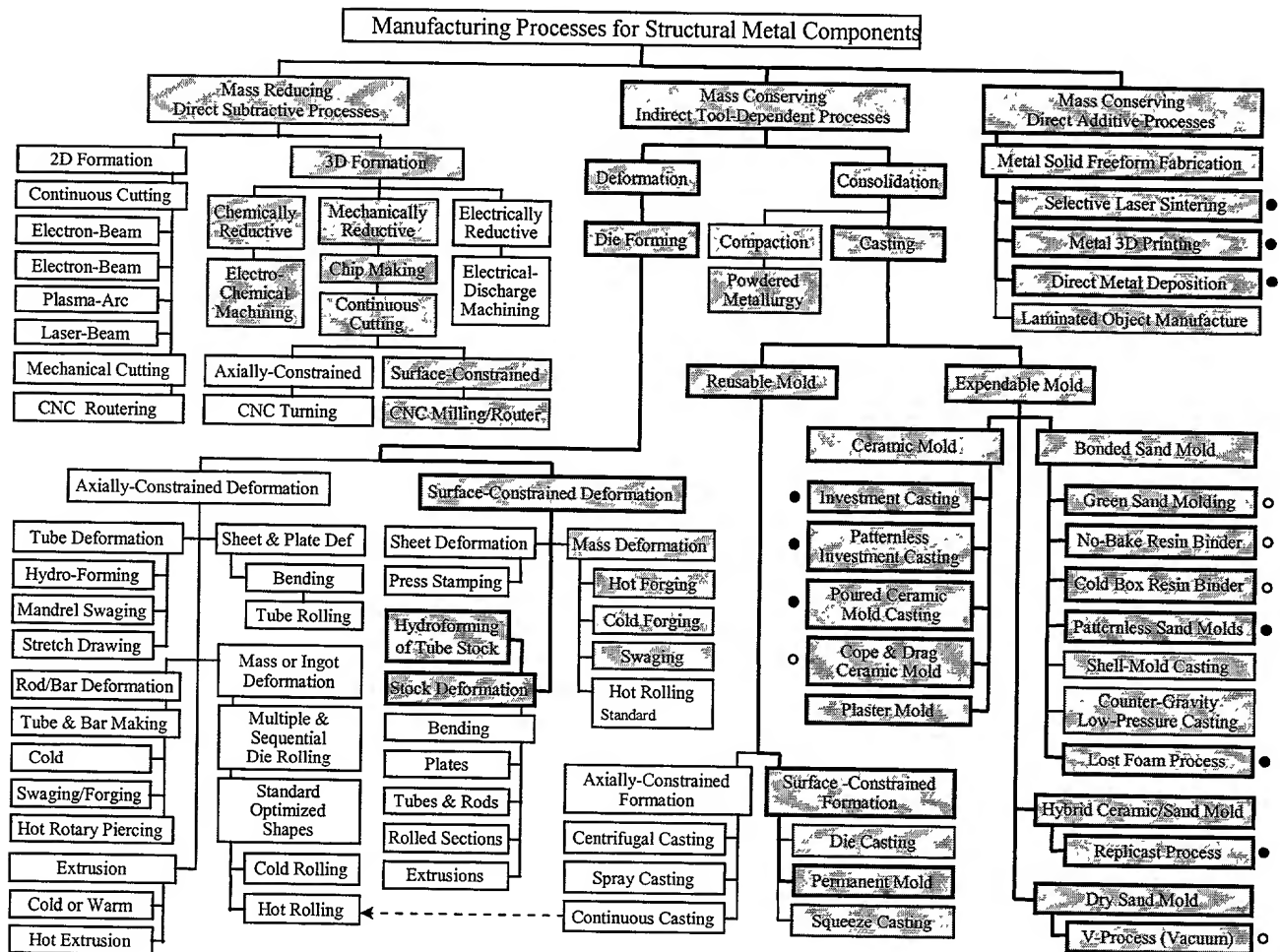


FIG. 7

FIG. 8



- Process with Capacity to Produce Complexly-Shaped Solid Components.
- Process with Capacity to Produce Complexly-Shaped Tubular as well as Solid Components.
- Process with Capacity to Produce Complexly-Shaped Tubes with Very Limited Internal Features.
- Process with Capacity to Produce Complexly-Shaped Tubes with Extensive Internal Features.
- Process with No Capacity to Produce Complexly-Shaped Solid or Tubular Components.

Tooling Classification						Process Status	Fundamental Computer-Aided Manufacturing Processes for Complexly-Shaped Metal Structural Components:	Capacity to Produce Freeform Components: ■ Capacity □ Limited Capacity	Complexly-Shaped Solids	Freeform Tubes	Tubes w/Internal Features
Hard Die	Hard Mold	Soft Mold	Expendable Mold	Hard Pattern	Expendable Pattern						
						Established	Direct Production Processes:				
						●	1 3D Data → Additive Formation → Component		■	■	■
						●	2 3D Data → Subtractive Formation → Component		■		
						Emerging	Direct Expendable Mold Processes (Direct Tooling):				
			●			●	3 3D Data → Additive Formation → Expendable Mold → Component		■	■	■
			●			●	4 3D Data → Subtractive Formation → Expendable Mold → Component		■	■	□
						Established	Indirect Expendable Mold Processes:				
			●		●	●	5 3D Data → Additive Formation → Expendable Pattern → Expendable Mold → Component		■	■	■
			●		●	●	6 3D Data → Subtractive Formation → Expendable Pattern → Expendable Mold → Component		■	■	■
			●		●	●	7 3D Data → Subtractive Formation → Permanent Mold → Expendable Pattern → Expendable Mold → Component		■	■	□
			●		●	●	8 3D Data → Additive Formation → Net Shape Mold → Subtractive Formation → Permanent Mold → Expendable Pattern → Expendable Mold → Component		■	■	□
			●		●	●	9 3D Data → Additive Formation → Master Pattern → Expendable Mold → Component		■	■	□
			●		●	●	10 3D Data → Subtractive Formation → Master Pattern → Expendable Mold → Component		■	■	□
			●		●	●	11 3D Data → Additive Formation → Master Pattern → Short-Life Mold → Expendable Pattern → Expendable Mold → Component		■	■	□
			●		●	●	12 3D Data → Subtractive Formation → Master Pattern → Short-Life Mold → Expendable Pattern → Expendable Mold → Component		■	■	□
						Established	Direct Permanent Mold Production Processes:	Note: Permanent mold processes have the capacity to produce freeform metal tubes if sand cores are used, which is an established method. As with other pattern & mold-based processes, the capacity to produce internal features is limited by pattern or product removal.			
						●	13 3D Data → Additive Formation → Permanent Mold → Component		■	■	□
						●	14 3D Data → Additive Formation → Net Shape Mold → Subtractive Formation → Permanent Mold → Component		■	■	□
						●	15 3D Data → Subtractive Formation → Permanent Mold → Component		■	■	□
						Established	Direct Permanent Die Production Processes:				
						●	16 3D Data → Additive Formation → Permanent Die Set → Component		■		
						●	17 3D Data → Additive Formation → Net Shape Die Set → Subtractive Formation → Permanent Die Set → Component		■		
						●	18 3D Data → Subtractive Formation → Permanent Die Set → Component		■		
						Established	Indirect Permanent Die Production Processes:				
			●		●	●	19 3D Data → Additive Formation → Expendable Pattern → Expendable Mold → Net Shape Die Set → Subtractive Formation → Permanent Die Set → Component		■		
			●		●	●	20 3D Data → Subtractive Formation → Expendable Pattern → Expendable Mold → Net Shape Die Set → Subtractive Formation → Permanent Die Set → Component		■		
			●		●	●	21 3D Data → Subtractive Formation → Expendable Mold → Net Shape Die Set → Subtractive Formation → Permanent Die Set → Component		■		
			●		●	●	22 3D Data → Additive Formation → Master Pattern → Expendable Mold → Net Shape Die Set → Subtractive Formation → Permanent Die Set → Component		■		
			●		●	●	23 3D Data → Subtractive Formation → Master Pattern → Expendable Mold → Net Shape Die Set → Subtractive Formation → Permanent Die Set → Component		■		

FIG. 9

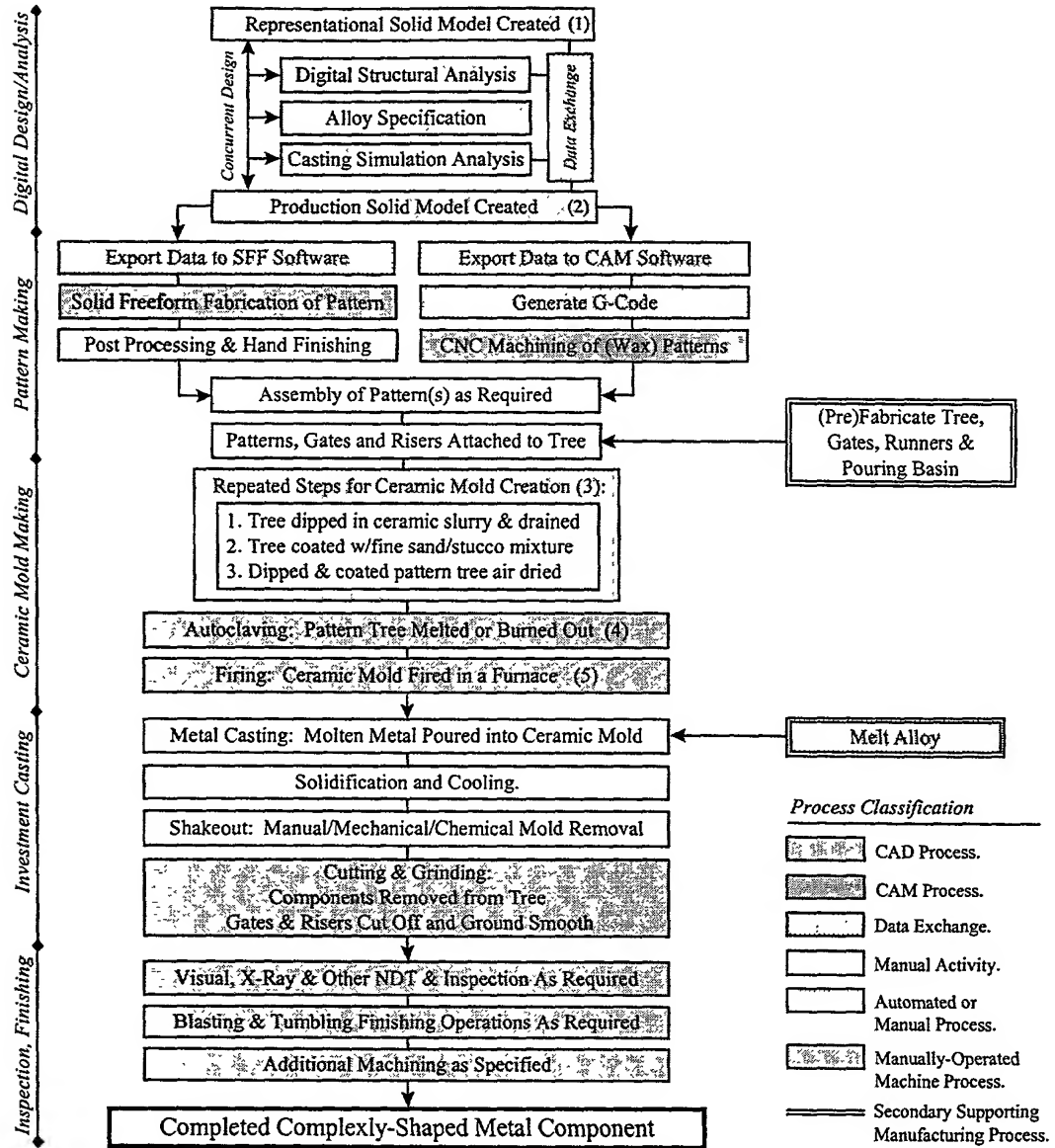
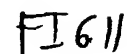


FIG 10



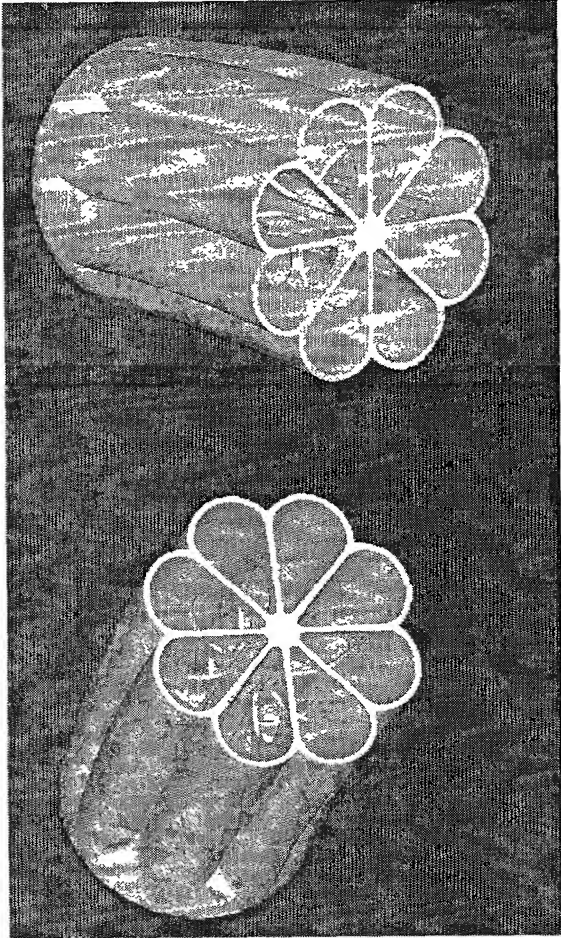


FIG. 12

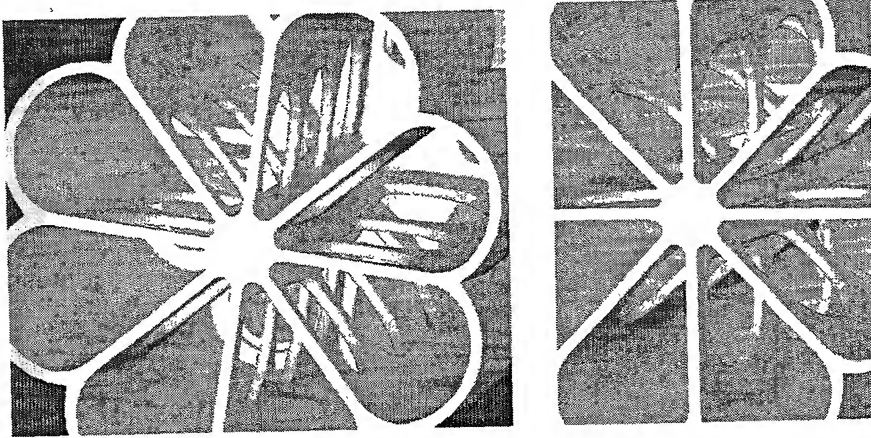


FIG. 13

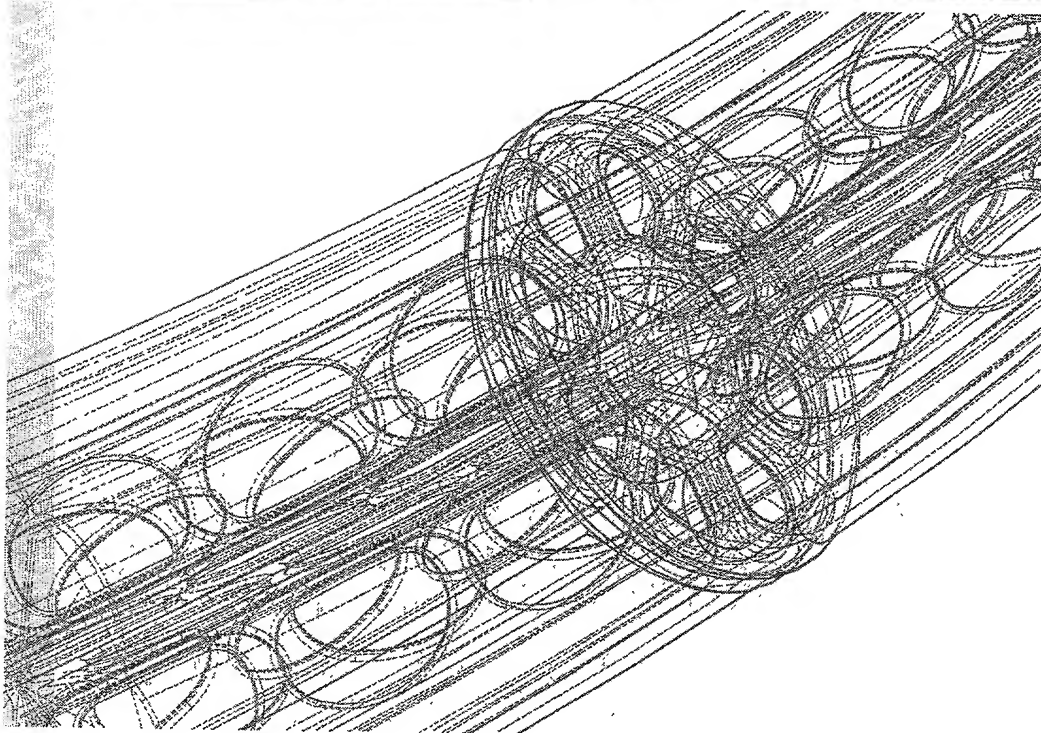
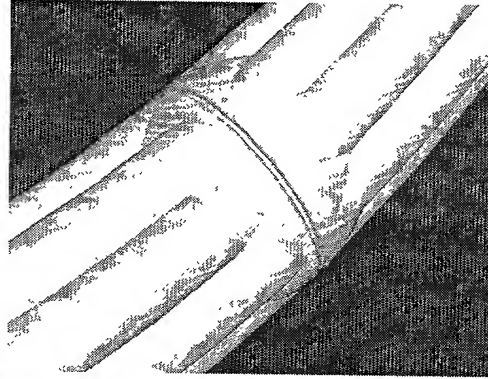
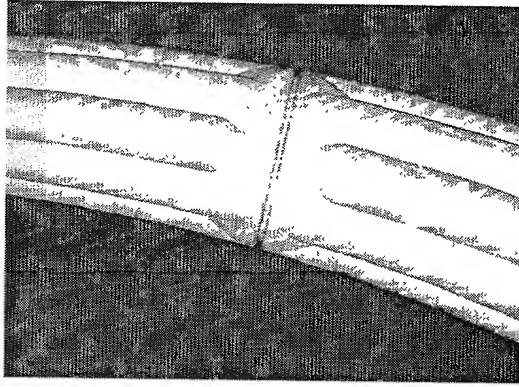


FIG. 14

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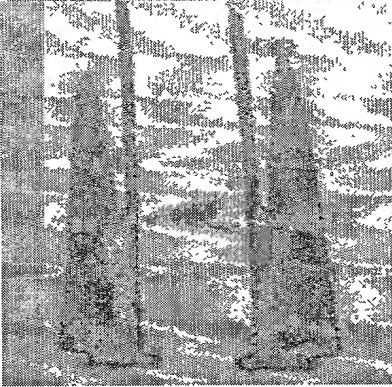
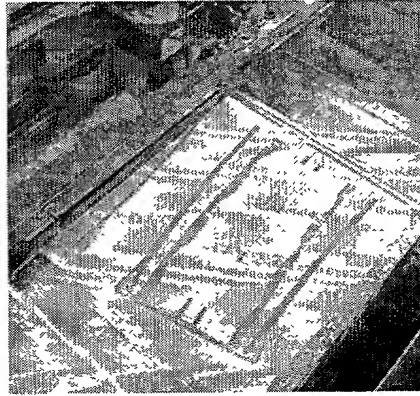
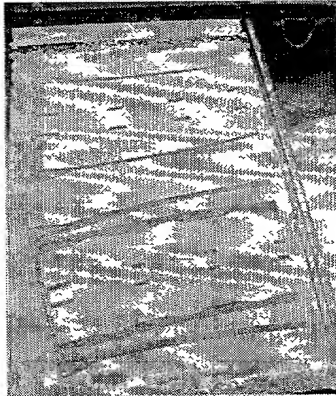


FIG 15

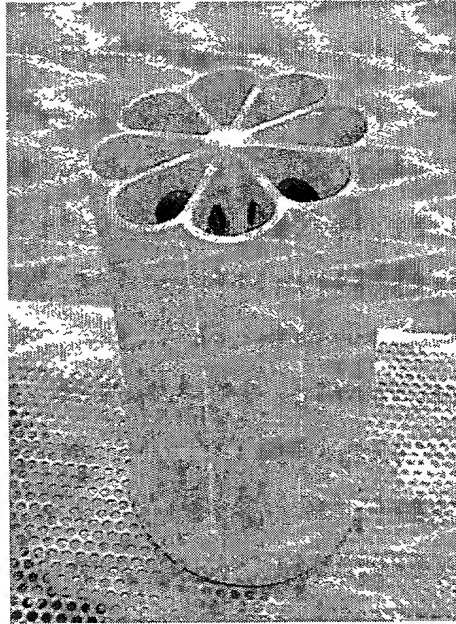
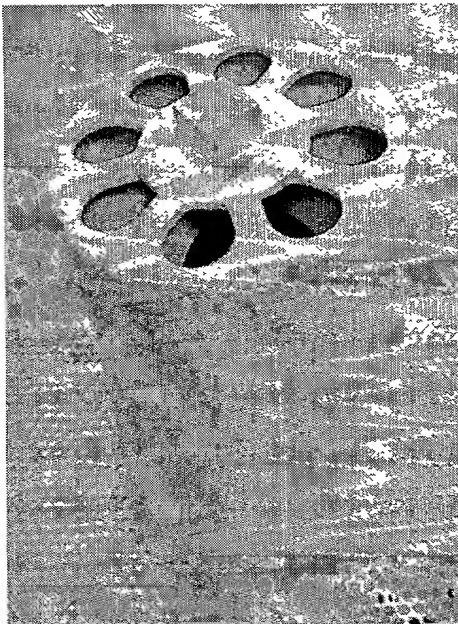


FIG. 16

FIG. 15

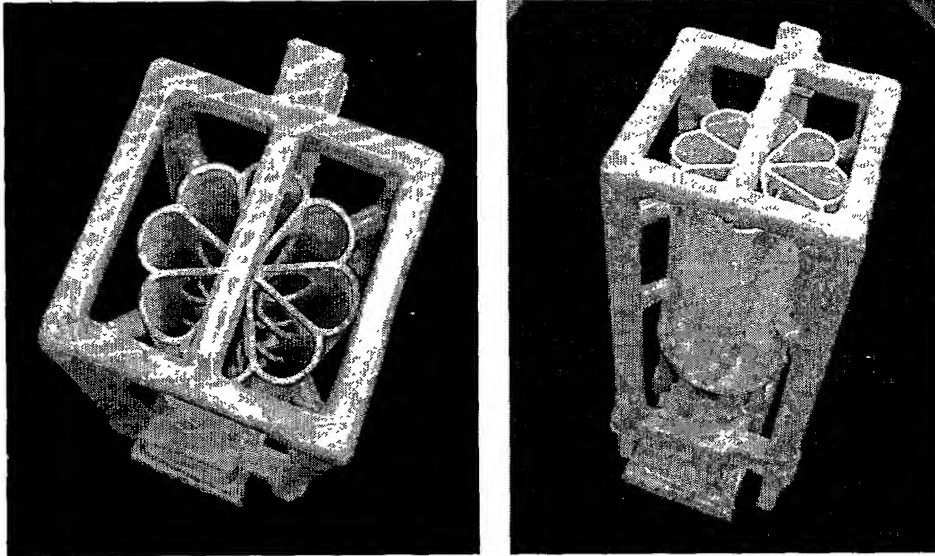


FIG. 17

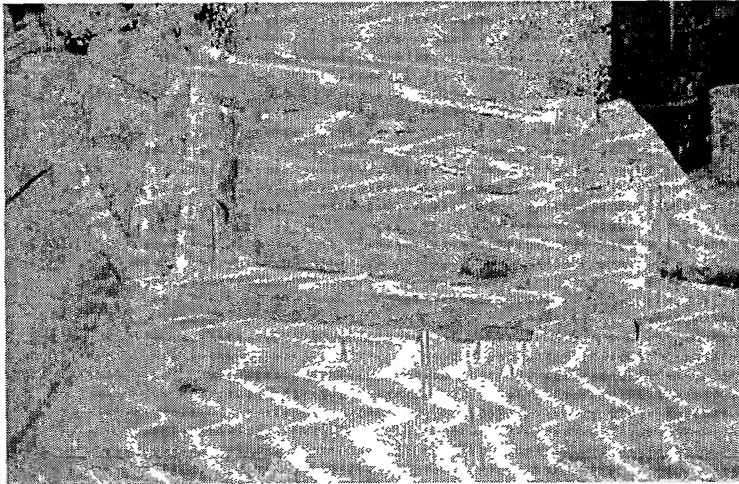


FIG. 18

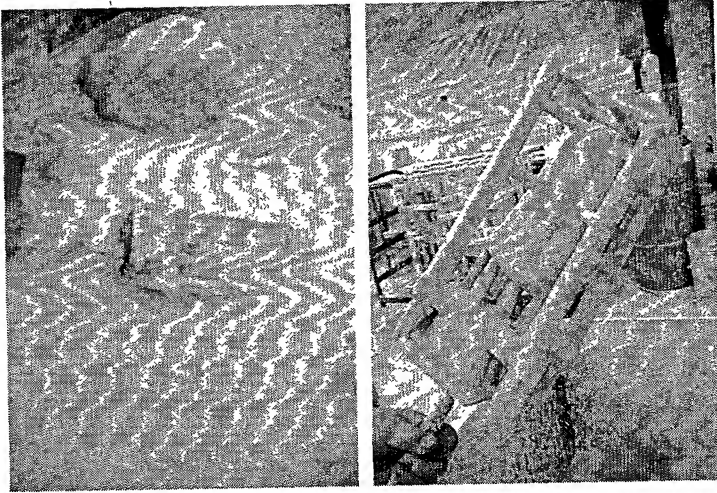


FIG. 19

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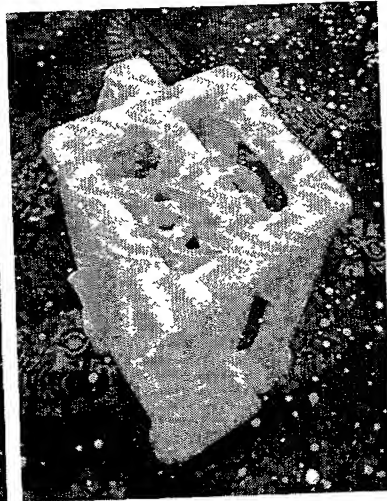
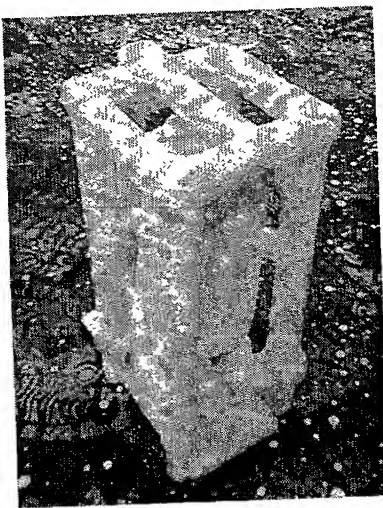
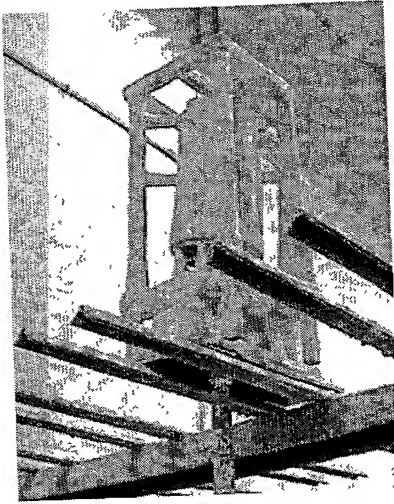


FIG. 20

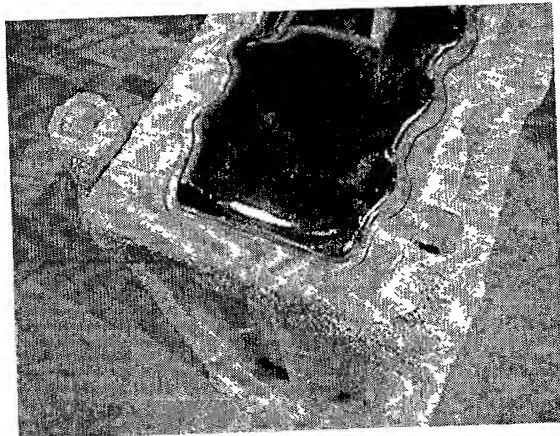
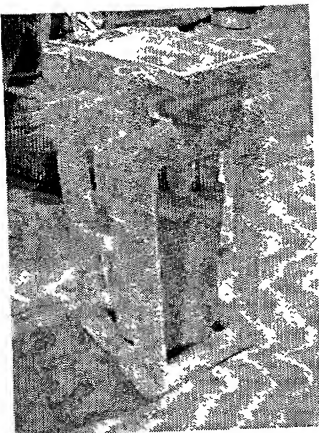


FIG. 21

FIG. 20

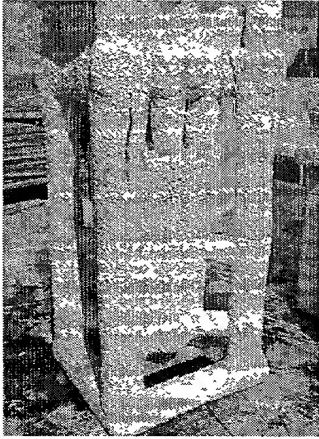


FIG. 22

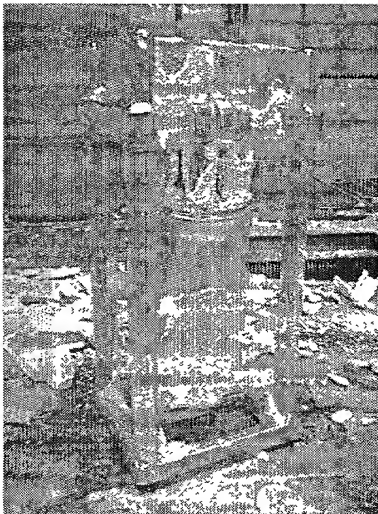


FIG. 23

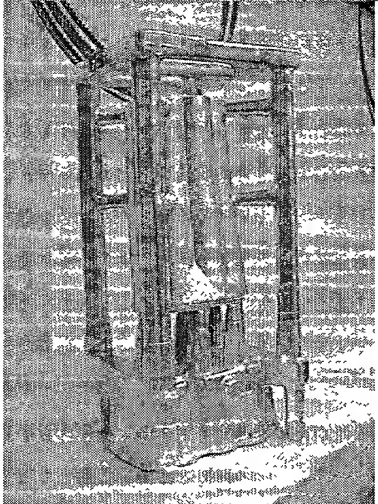


FIG. 24

FIG. 21

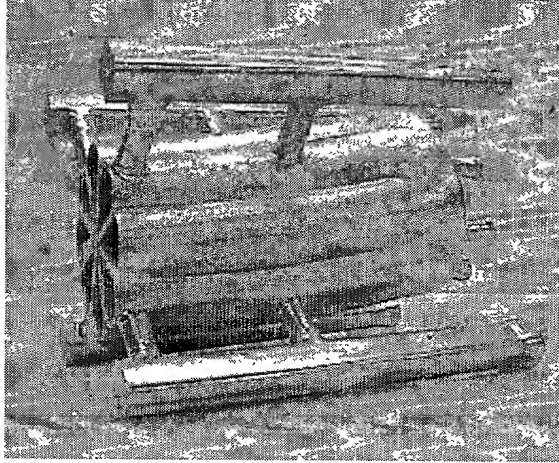
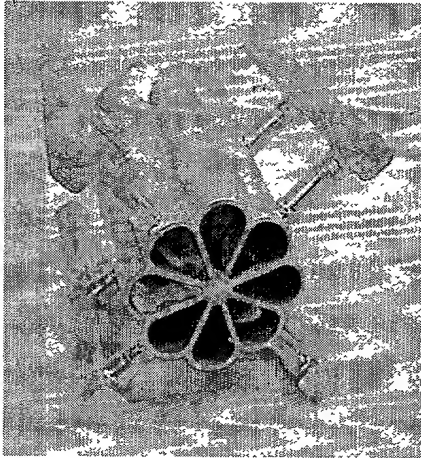


FIG. 25

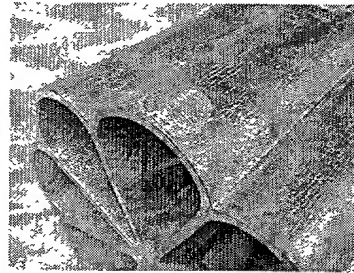
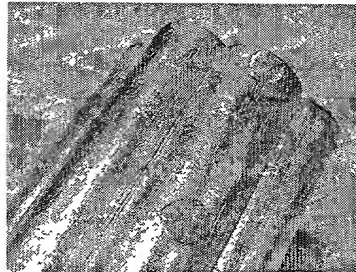
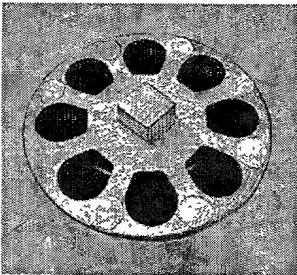


FIG. 26

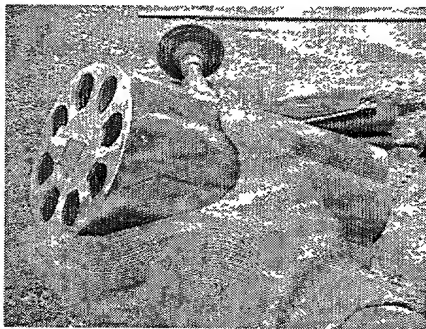


FIG. 27

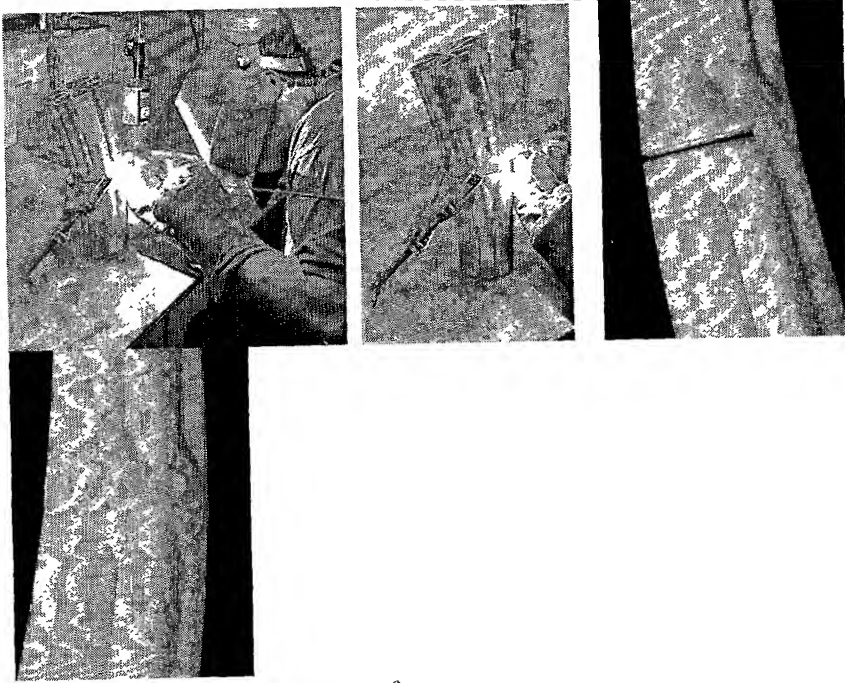


FIG. 28

FIG. 29

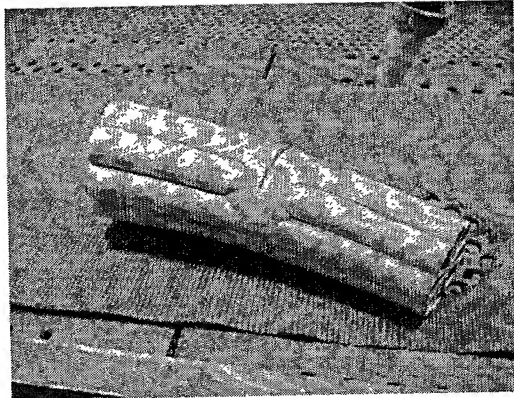
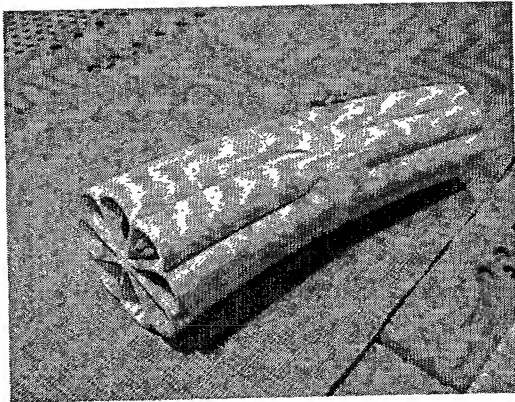
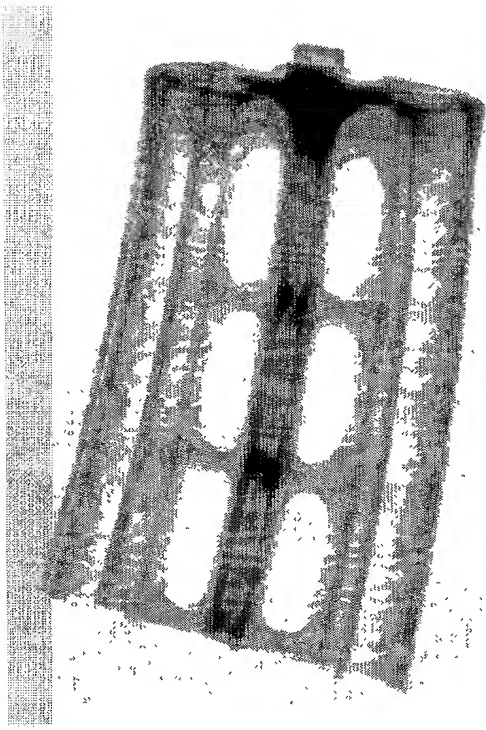
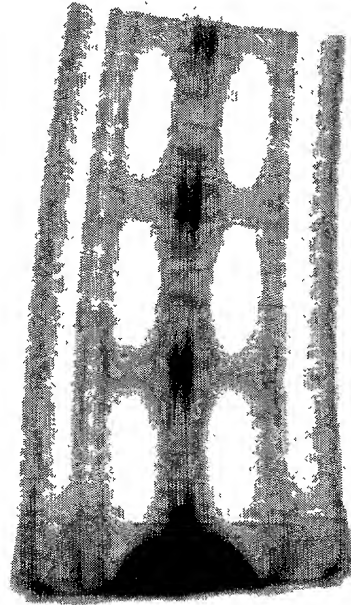


FIG. 30

UNITARY METAL STRUCTURE MEMBER WITH INTERNAL...



31A



31B

FIG. 31

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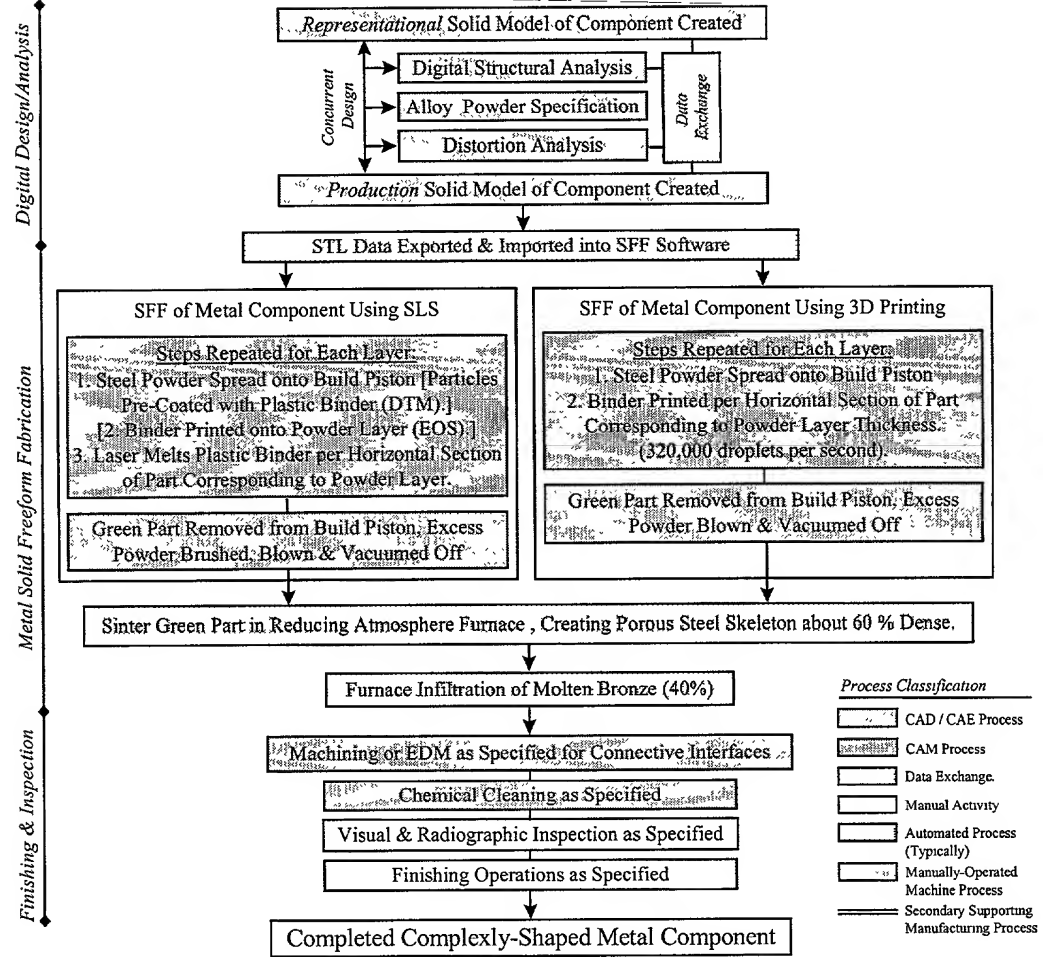


FIG. 32